NATO ASI NO: 951029

MAGNETIC HYSTERESIS IN NOVEL MAGNETIC MATERIALS
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The institute brought together scientists and engineers from many different backgrounds including hard and soft magnetic materials, small particles, thin films and multilayers, bulk magnets and magnet applications, and reviewed the past, current and future state of novel magnetic materials with emphasis on magnetic hysteresis.

In the last 50 years major advances in magnetic materials have been appearing at an accelerating pace. Permanent magnets have developed from AlNiCo's with $(BH)_m \sim 8$ MGOe and $H_c \sim 800$ Oe to the recently discovered Nd-Fe-B supermagnets with $H_c \sim 15$ kOe and $(BH)_m$ up to 54 MGOe. Soft magnetic materials have progressed from bulk electrical steels to amorphous metglasses (Fe-Si-B) and to the recently discovered nanocrystalline alloys (Fe-Zr-Cu-B) with much lower core losses and coercivities down to mOe. Particulate media for magnetic storage have progressed from CrO_2 and γ-Fe_2O_3 particles with $H_c \sim$ 300 Oe to particles with much higher coercivities such as Co-doped Fe_2O_3 (H_c 700 Oe), metallic Fe ($H_c \sim 2000$ Oe) and barium ferrite particles ($H_c \sim$ 2000-3000 Oe). The information storage density in magnetic media has changed from 2×10^6 bits/in^2 in 1975 to an estimated 10^{10} bits/in^2 by the year 2001 in thin film media with $H_c > 3000$ Oe. Recording heads have changed from the bulk soft permalloys and ferrites to thin films with high magnetization and giant magnetoresistance. In all of these materials coercivity is the key parameter which determines their application.

The ASI covered in detail the physics of the various hysteresis models which are currently used to explain the magnetization reversal process including coherent and incoherent magnetization processes, micromagnetism and its application in thin films, multilayers, nanowires, particles and bulk magnets, domain wall pinning and domain wall dynamics and Preisach modeling. An attempt was made to clear some of the wrong concepts and interpretations which still exist in the literature. Magnetic imaging techniques were reviewed including transmission electron microscopy (TEM), scanning electron microscopy (SEM), magnetic force microscopy, and optical microscopy. The temperature, field and angular dependence of coercivity, magnetic interactions and magnetic relaxation (magnetic viscosity) phenomena were reviewed and their effect on magnetic hysteresis was discussed.

The magnetic properties of (both soft and hard) novel materials, including nanoparticles, nanocrystalline granular solids, particulate media, thin films and multilayers and bulk magnets were discussed with emphasis on magnetic hysteresis and its relation to microstructure. Finally present and future applications of novel materials were discussed including magnetic and magnetooptic recording media, magnetoelectronics, sensors, magnetic circuit design and novel magnetic structures from rigid, high energy permanent magnets.

The comprehensive and multidisciplinary nature of the ASI made it very constructive and successful and we believe it will have a significant impact on novel materials and lead to the future design and discovery of better materials.

5. General Comments

The Director is asked to give here general comments on the meeting; comments on the application process, the planning and execution of the meeting itself and follow-up are also useful for the maintenance and improvement of the ASI Programme and are welcome. Specifically financial comments should not be given here but may be made in the accompanying financial report. A short scientific summary of the meeting should be prepared on the attached camera ready copy sheets for publication in the NATO Science Committee Yearbook.

The idea of holding a NATO ASI on magnetic hysteresis has been in my mind for the last few years. Magnetic hysteresis is a common property of ferromagnetic/ferrimagnetic materials in both hard and soft magnets and is observed in many novel materials currently in use including bulk magnets, small particles, and thin films/multilayers. Remarkable progress has been made in magnetic materials in the last 40 years, both scientifically and technologically with a world market having an annual value of several tens of billions of dollars. The emphasis currently is on nanocrystalline materials where progress rapidly accelerates. However, despite the significant progress, there is still confusion about the magnetic hardening models used to explain hysteresis, to the extent that researchers in different areas appear as if they are using different languages. A better understanding of hysteresis would contribute to the continuing success of these technologically important materials. To the best of my knowledge, there is not a single book devoted to magnetic hysteresis. Therefore, there was a clear and obvious need for an ASI devoted to this topic.

When we were notified of the ASI award (early November, 1995) we sent over 350 letters to individuals and groups involved in the research, development, production, and application of magnetic materials. We also sent e-mail to hundreds of magnetic researchers around the world, and established a home page on the World Wide Web. We advertised in the "Rare Earth News" and "Magnews." We posted notices at several conferences including the 95 Magnetism and Magnetic Materials Conference and the American Physical Society March Annual Meeting.

We received more than 240 applications. After careful review, we chose those whose interests most closely matched the topic of the ASI. However, even so we had to reject applicants with expertise in the same area because of the large number. (Some of these applicants came with their own expenses.) Also , a few of the applicants were requested to give a one hour lecture to complement and strengthen the program, especially regarding current research and technological applications.

We prepared a booklet containing the agenda, summaries of lectures, abstracts of invited talks and of posters, and participant address list and this was distributed to all participants upon their arrival at the ASI.

The program of the ASI was divided into the following sessions: Theory (in which all the magnetic hardening models were reviewed), Characterization Techniques (including magnetic and microstructural), Novel Materials and Microstructure (including hard and soft magnets in small particles, bulk, and thin films/multilayers) and Applications. Each session was comprised of lectures and invited talks, as well as a panel discussion. The moderator of each panel discussions talked to the students and speakers and gather questions from the students for further discussion. The discussion was opened to all the participants. Two poster sessions were also held, and over 60 papers were shown. We believe that this format ensured thorough coverage of each topic.

We believe that this was an excellent ASI. The lectures were of very high quality and genuinely tutorial in nature. The program was a balanced and comprehensive coverage of the topic of magnetic hysteresis in novel materials. The participants represented a diverse mixture of physicists, chemists, and materials scientists. Socially, the ASI was also successful. A welcoming reception, dinner galas and banquet, and excursions afforded the participants the chance to become acquainted with each other on an informal basis. We hope and believe that fruitful future scientific collaborations will result from this ASI.

Main Lectures Given

Coherent and Incoherent Magnetization Processes in Non-Interacting Particles
Dr. Amikam Aharoni, Weizmann Institute of Science, ISRAEL

Domain Wall Dynamics and Preisach Modeling
Dr. Giorgio Bertotti, IEN Galileo Ferraris, ITALY

Hysteresis in Particulate Materials
Dr. Roy W. Chantrell, University of Wales, UK

Imaging Magnetic Structures in the Transmission Electron Microscope; Domains, Domain Walls, and the Magnetization Reversal Process
Dr. John N. Chapman, University of Glasgow, UK

Hard Magnets and Their Microstructure
Dr. Josef Fidler, Technical University of Vienna, AUSTRIA

Amorphous and Nanocrystalline Soft Magnets,
Dr. Giselher Herzer, Vacuumschmetze GmBH, GERMANY

Nucleation Processes and Domain Wall Pinning in Modern Magnetic Materials
Dr. Helmut Kronmueller, Max-Planck-Institut fuer Metallforschung, GERMANY

Thin Film Longitudinal Magnetic Recording Media; Magnetic/Magneto-Optic Recording: Present and Future Trends
Dr. David N. Lambeth, Carnegie Mellon University, USA

An Introduction to Permanent Magnet Design; Novel Magnetic Structures Made Possible by Rigid, High Energy Permanent Magnets; Electric and Magnetic Fields in Material Media
Dr. Herbert Leupold, U.S. Army Electronics Technology & Devices Laboratory, USA

Micromagnetics of Thin Films and Multilayers
Dr. Thomas Schrefl, Technical University of Vienna, AUSTRIA

Magnetization Reversal in High Coercivity Nanocrystalline Films; Magneto-Optic Properties of Nanostructured Films and Multilayers
Dr. D.J. Sellmyer, Center for Materials Research and Analysis, USA

Particulate Media
Dr. Dennis Speliotis, Digital Measurement Systems, Inc., USA

Magnetic Viscosity and its Relation to Magnetic Hysteresis
Dr. Javier Tejada, University of Barcelona, SPAIN

Soft Magnetic Materials
Dr. Hans Warlimont, Institute for Solid State and Materials Research-Dresden, GERMANY

Organizing Committee

Dr. G.C. Hadjipanayis (Director), University of Delaware, USA

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